Improvement of Steering Feel
Virtual Approach with HiL

Steering feel plays a major part in the perception of handling characteristics and is increasingly gaining importance as a customer-relevant criterion and as an element of a brand's DNA of a car manufacturer. State-of-the-art simulation environments and Hardware-in-the-Loop (HiL) test rigs offer possibilities needed for a reproducible and efficient tuning process in laboratory conditions. Hyundai in cooperation with IPG Automotive has proved the feasibility of virtually tuning the parameters of an Electrically assisted Power Steering (EPS) system.

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CURRENT STATE

The main function of a steering system is to make a vehicle follow a desired trajectory with an acceptable amount of steering wheel torque. In addition, the driver should receive adequate feedback about vehicle and road conditions without being disturbed by unpleasant side effects. A high-quality steering system will make the driver feel safe and comfortable while emphasising the aspect of driving pleasure as well. To achieve this desired steering feel, the final tuning of a steering system is primarily performed in the full vehicle on proving grounds and public roads by experienced specialists of the vehicle manufacturer with support by the steering system supplier.

The majority of Hyundai Motor Group's (HMG) passenger cars is equipped with EPS systems. In the hatchback C-segment – such as the Hyundai i30 – the EPS system is installed on the steering column, **FIGURE 1**. Final tuning of steering assist is performed fully electronically by software. The tuning parameters are written to and stored in the integrated Electronic Control Unit (ECU).

MOTIVATION FOR PROCESS OPTIMISATION

The target of HMG is to consolidate the brand's identity in each segment and each characteristic including steering feel. Due to the diversity of the model line-up efficient and robust development processes are indispensable. This is particularly true for EPS tuning of steering feel by modifying software parameters, which can generate a nearly infinite combination of properties that influence the steering assist torque and thus steering feel. Shifting parts of the develop-

FIGURE 1 Hyundai i30 with column-type electrically assisted power steering

FIGURE 2 Objective tests on the proving ground with steering rack force measurement via strain gauges (DMS) on the tie rods

FIGURE 3 Vehicle specimen (left) on the suspension measurement device in order to test elastokinematics (K&C) at HMETC in Rüsselsheim and steering system (right) on the steering test bench of the Munich University of Applied Sciences

ment work from the proving ground and public roads to the laboratory and to computational simulation yields possibilities to save time and other resources.

HARDWARE-IN-THE-LOOP FOR A STEERING SYSTEM

Simulation tools make it possible to work independently of real-world vehicles, proving grounds or public roads, expert drivers and weather conditions. All test manoeuvres can be performed fast and without endangering people and material because the simulated vehicle can immediately and reproducibly be put into any desired driving condition in the virtual environment.

The CarMaker open integration and test platform from IPG Automotive enables the integration of virtual and real-world vehicle components in a virtual vehicle, as well as the quick and automatable modification of vehicle parameters such as weight, spring stiffness or damper characteristics, which often vary even within the same model range depending, for instance, on the powertrain configuration. As a result, component characteristics can be validated directly in the full-vehicle context.

HiL tests combine the advantages of test bench component testing with those of computational simulation. The HiL approach is mainly used for embedded real-time systems such as powertrain and vehicle dynamics ECUs in order to check their correct functionality, performance and diagnostic behaviour. Conventional HiL tests for mechanical subsystems such as steering systems are typically focused on safety and durability.

In the HiL test discussed here the steering system is located on the test bench as a real-world unit-under-test. Due to the use of real-world components the uncertainties inherent in such a complex system with its non-linearities (for example due to friction and due to the steering software that typically is available only as a black box provided by the supplier) can be excluded.

Theoretically, perfect reproducibilty of tests can be achieved by combining laboratory tests and the computational simulation of a validated vehicle model, allowing an isolated analysis of cause and effect.

EXPERT EVALUATION

Steering feel is usually evaluated subjectively by company test drivers, motor journalists and, at least on a subliminal level, by the consumer as well. Therefore, in an initial step an internal expert group of Hyundai Motor Europe Technical Center (HMETC) and IPG Automotive was established to define various aspects of steering feel and to determine differences in steering characteristics.

Various test sessions with benchmark and reference vehicles were organised on public roads and proving grounds. The result was a detailed comparison sheet indicating the areas to be worked on in order to achieve the desired target.

OBJECTIFICATION OF STEERING FEEL

Complete tuning by means of simulation can only be successful if it is based one hundred per cent on objective evaluation criteria since no real-world driver should be involved in the process. To generate these criteria and target values, the same vehicles that were subjectively evaluated in various driving manoeuvres were objectively compared in dynamic proving ground testing as well, **FIGURE 2**. The test cars were instrumented with inertial platform systems for acquisition of angular rates and accelerations, differential GPS sensors for longitudinal and lateral velocities, strain gauges on the tie rods for steering rack forces and a steering robot for repeatable steering input and steering angle and torque measurement. Selected data was analysed with the objective of generating reproducible target values in the most relevant areas of customer driving.

SETUP OF THE SIMULATION MODEL

From a vehicle dynamics and steering point of view suspension kinematics and compliance (K&C) characteristics provide the base of a vehicle's simulation model. The tests can be run on HMETC's in-house suspension parameter measurement device, **FIGURE 3**, in Rüsselsheim (Germany). They are required to generate look-

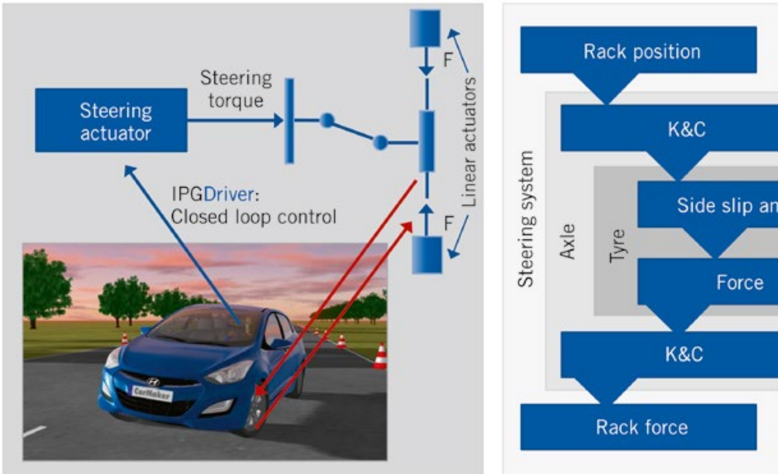

FIGURE 4 Hardware-in-the-Loop method for the steering system

up tables for the CarMaker's real-time model. Tyre data being provided by HMG's research centre in Namyang (South Korea). The validation of the full-vehicle model is performed against the same dynamic tests on the proving ground that were run to generate the steering feel target values. In addition to the vehicle's response to steering input (for example lateral acceleration), the tie rod forces have to be checked as well, to ensure that the testing conditions in the laboratory are realistic.

APPLICATION ON THE HIL STEERING TEST BENCH

With the objective targets defined and the real-time vehicle model validated, the full EPS system was installed on the steering system test bench of the Munich University of Applied Sciences (Germany). The environment of the real-world vehicle has to be emulated by applying the same geometrical connection hardpoints of the steering system on the test bench. The ECU requires power supply and a CAN interface. CAN bus signals (for example vehicle speed) are transmitted directly from the simulated vehicle on the real-time computer to the steering.

Steering angle input is provided through a rotating motor at the steering wheel. The translational motion of the tie rods is measured by the test bench and serves as input for the real-time model to determine the wheel position in reference to the road surface. With the resulting values in the tyre contact patch (footprint) CarMaker calculates both the vehicle's response and the resulting tie rod forces for the linear actuators. These forces are fed back into the steering system, generating a reaction torque at the steering wheel that is measured to close the control loop, **FIGURE 4**.

EPS PARAMETER SETTING IN THE LABORATORY

The steering parameters are tuned exactly as they are in the environment of the real-world vehicle. The ECU of the EPS is connected to a computer (PC) via an on-board-diagnostics (OBD) cable. The same software as in the traditional tuning in real-world road testing is run on this PC. The work in the laboratory makes it possible to perform a real-time analysis of the results using a proprietary software tool.

Based on the differences between the measurement and the target curves specific parameter tuning for quick and efficient achievement of target values is performed. Each new steering parameter set is immediately reviewed and iteratively modified, as needed, until all the targets have been achieved. At the end of the process one desired parameter set is generated that can be applied directly in the real-world vehicle.

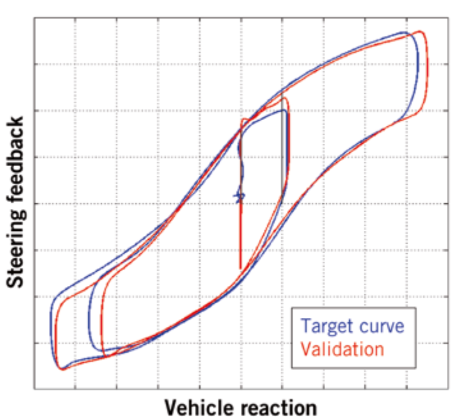

FIGURE 5 Validation of HiL parameter setting

VALIDATION OF RESULTS

Following the tuning period on the test bench, the same EPS system is re-installed in the real-world vehicle. Both the original and the final parameter sets are flashed on the EPS ECU. This is followed by repeating the objective tests on the proving ground to ensure that the targets achieved on the HiL test bench are matched in real-life conditions, **FIGURE 5**. However, the objective validation of measurements should only be viewed as an intermediate step as, ultimately, the subjective feeling of the driver counts. Therefore, in a final step, HMETC performed several subjective evaluations with experts from various internal departments and a neutral customer group. Both groups have confirmed the improvement in steering feel, and thus the suitability of the approach selected, as expected.

OUTLOOK

This initial feasibility study covered the most relevant aspects of customer driving. However, steering feel is important in any vehicle situation. There, the driving manoeuvres and target parameters have to be extended to higher lateral accelerations and higher steering wheel velocities. The HiL tuning process is already being implemented step-by-step as a helpful tool in tuning series production vehicles in order to support their efficiency and robustness.

Automation will be another major advantage of a fully objective tuning process supported by computational simulation. All tuning work in HiL testing is based on objective parameters and is clearly defined numerically as well. For this case HMETC and IPG Automotive are currently evaluating the possibilities of optimisation by Design of Experiments (DoE) to cover the full driving range. Ideally, this will lead to another great reduction in development time. Ultimately, the HiL process will be strongly supportive during the development of desired steering characteristics underlining the unique brand DNA for both Hyundai and Kia cars.